NAVY SHIPBOARD INVESTIGATION OF OILY WASTES

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ABSTRACT

The Navy's shipboard oily waste problem is defined. The nature, sources, and generation rates of oily waste produced by Naval ships while in port and at sea under various modes of operation are presented.

In surveys of bilge oily waste conducted on 32 ships, bilge fluid generation rates, while in-port cold iron, ranged from a low of approximately 3,000 gallons per day for various destroyers to a high of 80,000 gallons per day for an attack carrier. These fluids were characterized as approximately 99.9% water; oil films or layers amounted to 0.1% of the total bilge fluid volume. The water layer contained less than 91 parts per million oil and 34 milligrams per liter solids 90% of the time. The principal particulate constituents are defined as approximately 75% organic and 25% inorganic with the major inorganic elements comprised of iron oxide, zinc and aluminum.

Questionnaire surveys of nearly 500 ships, followed by some ship visits, indicate that approximately 10% of all shipboard oily waste is comprised of ballast waters of which 73% is contributed by oilers; over 50% of the remaining ship population accounts for less than 3% of the ballast oily waste.

Additional oily waste sources are defined. Principal bilge fluid sources are identified, and methods of reducing the volume of bilge fluids generated are explained. Survey data indicate that the major effort of the Navy's oil pollution abatement program should be the development of suitable shipboard oil-water separators.

INTRODUCTION

The Navy's stated goal in the area of oil pollution is a "complete halt of all discharge of oil and oily wastes into streams, harbors, and oceans by naval shore facilities and vessels."[1] To implement this, Navy ships must hold all oily waste until suitable shoreside storage is available, usually in the form of sludge barges or waste oil tank trucks. These techniques are costly and time consuming because of the present lack of suitable shipboard equipment to efficiently store and handle oily waste. To assist the ships in the implementation of these objectives, a series of surveys was conducted to determine the nature, sources, and generation rates of oily waste produced by Navy ships, while in port and at sea, under various modes of operation. This paper presents the results of these studies, particularly with regard to bilge and ballast oily waste.

Selection of ships for bilge fluid studies

Ships chosen for the survey were selected with a view to obtain maximum data from a small cross-section of the U.S. Fleet. Although only 32 ships, or 5% of the total Navy ship population, were surveyed, they represented 27 different ship classes and 19 distinct ship types. Over 50% of the Navy's combatant and auxiliary ships and crafts are to be found in the 19 ship types surveyed. In addition, an LST was selected for an in-depth survey because this was the largest ship in the fleet not driven by steam in terms of displacement, length, horsepower, and complexity of machinery plant. The generation rates obtained for this ship should be conservatively applicable to all the other smaller diesel and non steam-driven ships in the Navy, a group which accounts for another 25% of the fleet.

For some ship types more than one ship was surveyed. Two aircraft carriers were selected because it was recognized that these ships, which have the most complex machinery and propulsion plants, would probably have the highest bilge fluid generation rates. Because destroyers comprise approximately 20% of the present combatant fleet, nine destroyers were surveyed in depth to determine the variance with regard to generation rates among ships with similar propulsion plants.

Ship operation modes

The ship operation modes for which data were collected are broadly defined as follows.

In-port cold iron. The ship is receiving shore power, steam, and potable water. Some ships were at locations which had fire-main water available; others were required to run their fire pumps. Other than fire pumps, operating machinery was generally limited to low-pressure air compressors, air conditioning units and refrigerator units. Ship's personnel worked approximately 40 hours per week performing routine and more extensive programmed maintenance.

In-port auxiliary steaming. The ship is generating its own services at anchor or at a pier. Usually, the only operating machinery is that which is necessary to maintain the ship's services. For some ships, such as the tenders, auxiliary steaming was used for training the crew. During this time most machinery was in operation.

At sea. The ship is under way at various power levels. For most ships, approximately half of their boilers and associated auxiliaries were running while under way.

Generation rate determinations

Because of the scope of the surveys planned, the methodology made maximum use of the ship's force. Bilge-sounding sheets, which were filled out by ship's personnel, were developed for each class of ship surveyed. These data sheets listed specific locations to be sounded and provided data spaces for bilge soundings at each of these locations during every 4-hour watch. Ship's personnel also were requested to list the operating machinery in each compartment and to provide bilge fluid soundings before and after pumping bilges. All soundings were monitored by survey personnel at least

[1] OPNAV INSTR 6240.3C of 20 Apr 1973.

once a day when samples were being collected for fluid characterization studies.

The volume of bilge fluid generated was calculated from the soundings. Prior to the survey, curves of depth at center, or keel, versus volume were developed for each of the compartments of each ship class. These curves were obtained from hull or double-bottom configuration data and were corrected for all major machinery items, such as tanks and boilers. It was determined that approximately 5% of the gross volume can be attributed to pipe, equipment, and miscellaneous small structures in the bilge.

When volumes based on the curves were compared with volumes obtained from barge soundings after pump out, together with flow-meter readings when available, bilge generation totals agreed within 10%.

On some ships, either the work being conducted in the machinery spaces or the ship's operational schedule precluded the measurement of bilge fluid generation rates. For these ships, discussions were held with the ship's engineering personnel to determine how frequently they pumped bilges in each compartment and how high they normally allowed bilge fluid to rise before pumping down. Calculations of estimated bilge fluid generation rates were made on the basis of the volume at these levels and the estimated number of pump downs per given time period. Any data calculated in this matter are noted as estimated by operating personnel.

Bilge fluid characterization techniques

A "thief" type of device was used in sampling bilge fluids at each sounding location during the surveys to characterize bilge fluids in terms of oil and solids. For ships where fluid levels were allowed to rise rather high before pumping, samples of the water column beneath the surface oil layer were taken with this sampling device. It consisted of a 250-ml sample bottle which was unstoppered and stoppered underwater at a depth of 8 inches or more from the bottom. Stoppering beneath the fluid surface prevented water column samples from being contaminated with free surface oil when the bottle was withdrawn through the oil layer. For ships with normally low fluid levels, it was frequently necessary to submerge and unstopper the bottle by hand.

On two ships, more comprehensive sets of samples were taken at various locations and depths throughout a compartment to determine both the variance in bilge fluid and the variance due to the sampling technique. The water column samples were analyzed for oil and for suspended solids. Oil was analyzed by carbon tetrachloride extraction and infrared spectrometry. Suspended solids were determined by filtration with Whatman no. 1 paper and by weighing. The surface layer of oil was quantified either by measuring its thickness or by visually describing its extent before and after pumping and daily for each machinery compartment of each ship. When oil layers were present, the thickness of the oil layer was determined by using a water-sensitive paste which indicated the interface between the oil and water. In most instances the oil layer was merely a film and its thickness could not be measured accurately.

A simple laboratory experiment was performed to determine both the volume of oil contained in a representative continuous oil film and the volume of oil contained in one that could be easily broken by minor agitation. Table 1 presents the results of this experiment.

When oil films were present, survey personnel described the extent of the film as continuous, 50%, 10%, etc., and indicated whether or not it was readily broken by mechanically moving the surface film. These descriptions were used with the film volume of

Table 1. Oil film thickness data

	Volume of Oil, Gal/ft^2	
Type of Oil	To Form a Continuous Film	To Form a Readily Broken Film
Navy Distillate	0.007	0.008
Navy Special Fuel Oil	0.008	0.010
Navy Steam Turbine Lubricating Oil	0.012	0.016

0.016 gal/ft^2 to estimate the volume of free oil. For ships with large flat double bottoms, this method results in high oil indications because, when the bilge is pumped dry, the bilge bottom is usually extensively coated with an oil film and this same oil is noted again as a "new" film the next time the bilge fluid level builds up.

Machinery and bilge fluid handling data

Machinery and bilge fluid-handling data were obtained from discussions with ships' forces and by observing machinery in operation. Sources of fluid to the bilge were identified, and attempts were made to correlate these sources with generation rates. Ship's procedures for off-loading and transferring bilge oily waste were recorded. Additional data were obtained on many of the ships from the "smooth engineering logs." These data included the feedwater reports for at-sea and auxiliary steaming conditions.

Generation rates

The bilge sounding sheets from each ship were collected and used to calculate the overall generation rates. Table 2 lists these rates by operational mode. The rates which were based upon estimates by ships' personnel are so noted.

The in-port fluid generation rates measured for the DDs, DEs and DDGs ranged from 2,250 to 5,900 gal/d. The mean rate was 3,516 gal/d with a standard deviation of 1,130 gal/d The variation between different classes of destroyers in port was no larger than the variation within the DD 692/710 class destroyers. Thus all the destroyers could be described as being similar in generation rates; and ships of the same type, which were approximately the same size and had similar power plants, were grouped in the same generation rate categories.

With this information used as an assumption, Navy ship types were assigned to generation rate categories based on actual survey data, size and design of the power plant, ship mission, and ship size and shaft horsepower. Table 3 lists these general categories and their assumed rates.

Table 2. Survey results, bilge fluid generation rates

	Generation Rates, Gal/d		
Ship Surveyed	In Port Cold-Iron	In-Port Auxiliary Steaming	At Sea
AD 27 YELLOWSTONE	4,800	13,250	11,400
AE 19 DIAMOND HEAD	4,150		
AF 52 ARCTURUS	4,000*		
AF 56 DENEBOLA	9,300 6,200*		
AFS 6 SAN DIEGO	4,900 4,850*		
AO 143 NEOSHO	21,000		31,000
AR 5 VULCAN	14,200 37,000*		
ATF 160 PAPAGO			50*
CVA 60 SARATOGA	79,000	139,000	
CVA 63 KITTY HAWK	33,000	135,000	191,000 to 245,000
DD 758 STRONG	3,100		15,800
DD 849 KRAUS	5,900		
DD 878 VESOLE	3,800		
DD 881 BORDELON	2,250		
DD 888 STICKELL	600*		
DD 943 BLANDY	330*		
DDG 18 SEMMES	3,350		
DE 1056 CONNOLE	9,250*		
DE 1068 VREELAND	3,100		10,500
DE 1072 BLAKELY	2,600		
DLG 8 MACDONOUGH	2,900		
DLG 28 WAINWRIGHT	4,650		
LKA 113 CHARLESTON	20,000* to 40,000*		
LPD 11 CORONADO	22,600 45,000*	31,500	
LPH 12 INCHON	5,900* to 11,000*		
LSD 32 SPIEGEL GROVE	4,880		
LST 1171 DESOTO COUNTY	1,120*		
LST 1179 BOULDER	500	2,000	3,450
MSO 443 FIDELITY			2,5[illegible]
[illegible]TB 766 WAPUAKINETA	50*		300*

*Estimated by ship personnel

Table 3. In-port bilge water generation rates by categories

Ship Category	Rates (Gal/d) Cold-iron	Auxiliary Steaming
Aircraft carriers	79,000	139,000
Oilers and large amphibious ships	21,000	25,000
Replenishment ships, cruisers	15,000	20,000
Tenders, medium amphibious ships	4,800	13,250
Destroyers	3,500	10,000
Large diesel ships	500	2,000
Submarines	500	1,000
Patrol craft	100	400

Characterization of bilge fluids

Survey results and sample analyses indicate that, while ships are in port and not subject to appreciable motion, the bilges act as a gravity separator, and the bilge fluid constituents separate into several distinct layers.

1. A surface layer is one which usually consists of a thin film of oil, but at times, because of an oil spill or leak, may contain as much as several thousand gallons. Associated with this oil is a variable quantity of particulates which form an organic scum which interfaces this layer and the lower water layer.
2. A water layer contains little oil and few suspended solids. Tables 4 and 5 present the actual concentrations measured in this layer.
3. A sediment layer consists of accumulated settled solids ranging from minor amounts to a thickness of several inches.

An estimate of the total oil found in all the bilge fluids was made by combining the volume of oil contained in the surface layer and the highest concentration found 95% of the time in the water layer. During cold-iron in-port conditions, a total of 279 gallons of free surface oil was generated by all of the surveyed ships. The concentration of oil in the water layer was 149 p/m, or less, 95% of the time (44 gallons of oil). Thus, approximately 0.1% (or 323 gallons) of the 297,129 gallons of bilge fluid encountered during these surveys was estimated as oil.

Table 4 indicates that if ships had suitable real time bilge fluid monitors, it would be possible to pump the water layer directly overboard and be below the 15 p/m, or no visible sheen bilge fluid criteria, over 50% of the time. A similar monitor, if employed at sea, would allow pumping of bilge fluids overboard 74% of the time.

The natural settling effect of the bilge also resulted in two distinct types of fluids during the pumping out of bilge fluid: (1) a "normal" phase consisting of the water layer, and (2) an "end-of-pumpdown" phase consisting of the surface layer and the sediment layer which was agitated or washed by the last gallons of bilge fluid as they were pumped. Table 6 presents data taken from the analysis of samples from 15 normal phases and 2 end-of-pumpdown phases.

Only 20% to 30% of the total solids filtered from either phase were nonvolatile, indicating that approximately 75% of the solids in bilge fluids are organic.

Six samples of bilge water containing large amounts of solids were taken and analyzed to determine the amount of solids which could be removed by centrifugation. These samples were split. The first half was filtered through Whatman 1 filter paper and then through 1.2-μm Millipore filter membrane; the second half was centrifuged for 30 minutes in a 1,000 r/min, 6-inch-radius laboratory centrifuge and then was filtered first through Whatman 1 and then through 1.2-μm Millipore filters. Table 7 presents the results of these tests.

These data show that only 40% to 60% of the particulate matter can be removed by centrifugation, indicating that filtration of solids will still be required to protect conventional coalescers. The solid material which does not separate by centrifugation is believed to be small-diameter, oil-coated particles which float or are neutrally buoyant and microorganisms which exist in the bilge fluids.

Processing of the bilge oily wastes indicates that while in port an oily waste separator should take advantage of the natural settling which occurs in the bilge and either divert to storage or hold the bulk oil which has risen to the surface rather than processing it with the water layer. This, in effect, will eliminate most particulate matter which may tend to clog filter/coalescers.

Table 4. Analysis of oil samples

Operational Mode	No. of Samples	% of Samples 15 p/m & Below	100 p/m & Below	p/m Level Below Which 50% of Samples are	95% of Samples are
Cold Iron	430	51	93	14	79
Auxiliary Steaming	27	75	100	11	33
At-Sea	66	28	74	41	170
All	523	48	91	16	91

Table 5. Analysis of suspended solids

Operational Mode	No. of Samples	mg/l Level Below Which 50% of Samples are	95% of Samples are
Cold-Iron	135	12	32
Auxiliary Steaming	24	0	60
At-Sea	24	17	29
All	183	12	34

Table 6. Composition of bilge water

Test	Average of 15 Influent Samples	Average of 2 End-of-Pumpdown Samples
Total Suspended Solids, mg/l	32	1,407
Non-Volatile Suspended Solids, mg/l	9	564
Oil*, p/m	51	---
Fe, mg/l	2.05	130
Zn, mg/l	1.15	34.4
Al, mg/l	.07	10.3

*Results for oil were taken from duplicate samples. At end-of-pumpdown, bilge fluid could be 100% oil. However, the highest oil concentration noted during tests was 8%.

Sources of bilge fluid

The principal source of bilge fluid while the ships are cold iron is condensate from the ships' low-pressure drain system. This condensate comes from the shore-furnished steam which is used by the ship to run auxiliary equipment and hotel services, including heating and hot water. No means is available to return the condensate to shore, and it collects in the low-pressure drain-collecting tanks where it regularly overflows to the bilge. Some of the ships surveyed have recognized this as a large source of bilge fluid and have run pipelines from the low-pressure drains overboard. This only partially solves the problem, however, because the drain collecting tank is usually located low in the ship, below the external waterline, and a pump is required to transfer most of the condensate overboard.

Another source of bilge water is packing gland leak-off from rotary fire-pump seals. This source varied considerably from ship to ship and was noted as high as 4 gal/min on one ship prior to the overhaul of its pump seals.

There are also many operations which periodically dump large volumes of water into the bilge. These operations include washing boiler fire sides (every 600 hours of boiler operation) or water sides (every 1,800 hours of boiler operation), washing of decks or bilges, and hydrostatically testing equipment. Additional sources of wastewater are drains from sinks and drinking fountains which are located in many of the machinery spaces and drain to the bilge.

Principal oil buildups in port were caused by maintenance of systems containing oil, or failure of a portion of oil piping. Very little of the free surface oil generated while in port could be attributed to leakage of seals or valves. In many cases, bilge fluid had a film of oil on the surface when the ship came into port even though the ship attempted to pump bilges completely dry while at sea prior to arriving in port.

Table 7. Particulate analysis, centrifuge test

Sample No.	Weight of Solids, mg/l — Not Centrifuged, Retained by Whatman 1	1.2μm	Total	After Centrifuging, Retained by Whatman 1	1.2μm	Total
1	96	42	138	10	29	39
2	62	18	80	28	24	52
3	143	13	156	41	10	51
4	90	18	108	50	13	63
5	235	108	343	135	40	175
6	89	39	128	24	28	52
Average	117	39	158	48	24	72

Auxiliary steaming in port and the at-sea condition are very similar operational modes with respect to fluid generation and normally will only differ by the amount of machinery running. When in operation, most of the pump seals and many of the valve stems leaked small amounts. The only significant machinery seal leakage of this type was from fire pumps.

The major source of fluid to the bilges can be attributed to evaporator dumps and potable or feedwater tank overflows. Evaporator water distillate is either monitored automatically by saline indicators or is fed to a test tank and then tested by the operator. In either case, if the water is unsatisfactory (greater than 2-3 p/m chloride) it is dumped to the bilge. Dumping usually occurs initially for periods varying from several minutes to several hours when the evaporators are started and when the evaporators are in operation, perhaps only an hour a day total. The rate of dump is the same as the rate at which the evaporator produces water. If the evaporator water is satisfactory, it is pumped either to feedwater tanks or to potable water tanks to be stored for future use. These tanks do not have level alarms and frequently overflow before evaporator water is switched to another tank. Evaporator dumps and the feed or potable water tank overflows are the major contributors to bilge fluid volumes when machinery is in operation.

A primary source of oil in the bilges on some destroyers was sediment or sludge from the lube oil purifiers. On most ships the sludge went to a waste oil tank, but in some cases it went directly to the bilge, and in many cases, the overflow of the waste oil tank also went directly to the bilge.

Maintenance and cleaning of lube oil purifiers, strainers, and coolers at times may be an inadvertent source of oil especially on diesel ships. Other operations contributing oil to the bilge included maintenance of diesel engines, including changing and draining of the lube and fuel oil systems. Oil in the bilges also resulted from minor piping and valve leaks and infrequent piping failures that caused large volumes of oil to be dumped to the bilge.

Ballasting questionnaire

To determine the magnitude and extent of the Navy's oily ballast waste problem, a questionnaire was sent to over 500 ships in the active fleet. This questionnaire attempted to obtain ballasting history, data, capabilities, and procedures from the ships' records and personnel. Specific areas of interest included:

1. the number of refueling operations conducted during the past year
2. the quantity of fuel on hand prior to any refueling operation
3. the number of ballast-deballast operations conducted during the past year
4. the volume of water used by the ship for each complete ballast operation
5. the policies, regulations, and procedures which the ships follow in determining the need to ballast any fuel tank
6. the equipment and/or systems which are available for ballasting and deballasting operations
7. any additional comments the ship's personnel had concerning abating shipboard oil pollution problems.

Complete questionnaires were received from 486 ships. Table 8 presents a summary of these data arranged by ship type.

Table 9 presents a summation of ballast water generated by major contributors. These data indicate that the oilers, which account for less than 10% of the Navy's ship population, are responsible for the majority of all ballast water. Over half of the fleet generates a mere 3% of the total ballast water.

Table 8. Ballasting data by ship type

Ship Type	Number of Ships Reporting	Average Fuel % Prior to Refueling	Ballasting Operations Per Year Per Ship	Volume Per Ballasting in Gallons
Oilers	40	45	3.2	1,162,000
Carriers	21	70	0	0
Surface Combatants	201	63	3.7	32,000
Ocean* Escorts	40	67	.7	24,000
Amphibious	39	65	.1	62,000
Mine Warfare	65	66	.1	45,000
Other Auxiliaries	80	71	.6	63,000

*Excluding ships with compensated fuel/ballast sytems

Table 9. Ballasting water generation summary

Ship Category	Percent of Total Ballast Water
Oilers	73
Compensated Ships	13
Surface Combatants	11
Remaining Ships (over 50% of fleet)	3

Ballasting policies

All of the engineering officers contacted indicated that the oilers did not ballast as a normal routine and would normally require a set of unusual liquid-loading conditions prior to ballasting. Generally, the ships will try to schedule consolidations or fuel lifts to preclude the possibility of entering a liquid load condition wherein they must ballast. The decision to ballast is operational, based upon the careful weighing of many factors including the following:

1. hull structural stresses caused by liquid loading
2. damage control criteria
3. stability and ship handling considerations
4. fuel quality requirements
5. pollution dangers
6. ship scheduling.

Other oily waste sources

Stripping is performed to remove water, sediment, and contaminated fuel which has settled to the bottom of cargo tanks. All of the ships contacted had combined suction and stripping mains which can be used to take suction on a tank when refueling or transferring fuel, or they can be used for stripping a tank. This combined main is a single pipe of large diameter with two suction bell mouths, one a high suction for normal operations, the other a low suction for stripping operations. The elevation difference between the high and low suctions is approximately one foot. This elevation difference is designed to enable the lowering of any water or contaminant to a level below that of the primary suction, thus preventing water and contaminants from being transferred. These stripping lines do not remove all of the bulk water because they are approximately six inches above the tank bottoms. Similarly, prior to ballasting, these stripping lines or low suctions are too high to remove all of the oil in the tank. It is estimated that approximately 500 gallons of fluid will remain in most cargo tanks after stripping them "dry." In addition, the large (14-inch diameter) transfer mains which must be used to strip the tanks hold approximately 7 gallons per foot of length. These lines can hold several hundred gallons of the last fluid pumped, constituting both a source of potential pollution and a source of cargo or fluid contamination.

Attempts are made by oilers to designate contaminated tanks for each of the major cargo categories. There are times, however, especially after a fuel lift at sea, when no tanks are available to strip into and strippings will have to go into another tank with a less refined product.

Tank cleaning is another operation which generates oily waste. It is normally performed by butterworthing, a process of washing the tank walls with a portable rotating nozzle which delivers jets of steam-heated seawater at temperatures and pressure of approximately 175°F and 150 lb/in^2. Drop schedules, which detail the time period the tank cleaning machine is kept at each level, are usually followed. A typical drop schedule may take approximately two hours and create a volume of oily waste as large as 20% of the total volume of the tank being cleaned.

After butterworthing, the oily tank cleaning wastes are either pumped overboard or to a contaminated tank. Since considerable bottom sediment and liquid are left in the bottom of the tank (especially with NSFO), the tanks must then be pumped dry by using portable pumps or small portable suction hoses and then mucked out. The mucking out consists of manually scraping and

cleaning sediment, sludge, and rust from the tank bottom and walls, removing this material with buckets, and then performing a final washdown with a fire hose and wiping clean with rags. Engineering personnel indicated that the mucking process was much simpler with ND than with NSFO, because considerably less sludge was present.

Tank cleaning procedures are used prior to converting a tank to a more refined product. In addition, they are usually performed as routine maintenance approximately once a year on each tank. Because of the manpower required to clean the tanks and the restrictions on pumping oily wastes overboard in port areas, tank cleaning is normally performed at sea or in shipyards where suitable storage is available.

Total shipboard oily waste

The data obtained in these surveys provided totals of shipboard generated oily waste which must be processed at all U.S. port areas. Figure 1 summarizes these data. The bilge oily waste volume generated at each major port area was calculated on the basis of ship population and steaming records, and the bilge generation rates for the various ships are shown in table 3. The ballast and tank-cleaning volumes were calculated under the assumption that all of these wastes would be returned to port for processing.

This graph dramatically illustrates the relative magnitudes of the bilge/ballast oily waste generated by Navy ships. Although work is being pursued in all areas of oil pollution abatement, the major thrust of the Navy's oil pollution program is directed at reducing and treating this bilge oily waste.

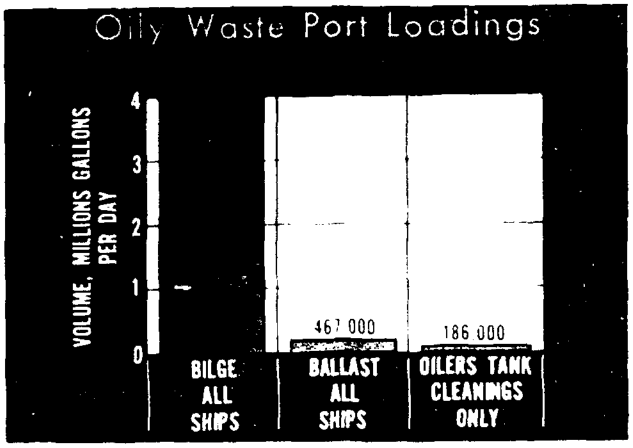

Figure 1. Oily waste port loadings

Ship alterations that will reduce the volume of oily waste in the bilges are being accomplished. For instance uncontaminated water is piped directly overboard instead of to the bilges. Changes to machinery are being implemented to reduce the volume of fluids generated. Of more potentially far-reaching importance, however, is the series of evaluations of the most promising oil-water separators. Shipboard testing is now going on with the aim of their future use on all Navy ships.

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